CHAPTER 3

TECHNICAL NOTES

A. A STUDY ON THE VALUE OF THREE-HOURLY FIXES

1. INTRODUCTION

At the 1971 PACOM Tropical Cyclone Conference a proposal to increase fix frequency from four per day to eight per day under certain circumstances was recommended for CINCPAC approval. This increased frequency was to apply when a typhoon threatened a major DOD installation in WESTPAC. CINCPAC approved this recommendation during April 1971.

The underlying reason for this change was a response to operational commanders' expressed desires, more to monitor track and intensity rather than improve forecasts. A study by Hope (1971) suggests that more frequent fixes reduces initial position error. Since short range forecasting (12 to 24 hours) is almost entirely extrapolation, one should expect to see a corresponding reduction in 12- to 24-hour forecast errors. Hope's work applied to Atlantic hurricanes, and differences in operational procedures suggest that his results might not apply to Pacific typhoons.

The hurricane initial position is based on a fix made two hours after warning time; in other words, the initial position is an interpolation between known points. The JTWC initial position is based on a fix made two hours before warning time, thus the initial position is an extrapolation. Increased sampling necessarily improves interpolation but not extrapolation. Extrapolation suffers when the sampling interval becomes so small that inaccuracies in measurements are of the same order of magnitude as likely changes in the measured parameter between samples. For example, if fix accuracy is about 12 miles and the indicated typhoon movement 12 kt, the actual speed between fixes at three-hourly intervals could be 4-20 kt and 8-16 kt at six-hourly intervals. Thus from a position uncertainty of 12 miles, a three-hourly movement extrapolated forward for two hours will add 16 miles where a six-hourly movement extrapolated would add 8 miles to this uncertainty. In interpolation the maximum uncertainty is limited by the average of the errors in the fixes on either side of the interpolated position.

At JTWC 12-hour movements are extrapolated when available, but when a key DOD installation is being threatened, it is difficult to totally ignore a shorter term movement if such indicates an increased threat.

The unusually heavy demand on reconnaissance during 1971 coupled with asset reduction forced abandonment of three-hourly fixes after October 1971, but a measure of the success of the program is desirable for future consideration.

2. A MEASURE OF IMPROVEMENT

By comparing forecasts based on three-hourly fixes to those made on six-hourly fixes, we should be able to measure the forecast improvement due solely to the increased fix frequency. In so doing, it becomes apparent that if an improvement is noted, that subsequent forecasts would be positively effected for a short while after cessation of three-hourly fixes; therefore, no forecasts made after cessation of three-hourly fixes were considered. Another possible red herring is that the three-hourly fixes are invariably made close to land. This implies a superior data area but is also an area where terrain influences are at work to degrade forecasts. To evaluate the effect of three-hourly fixes, it is first necessary to ascertain the effect on forecasts of typhoons approaching within 300 miles of key DOD installations without three-hourly fixes. This was done by using a control group of forecasts from 1968, 1969 and 1970. These forecasts were divided into sub-groups of those within 300 miles of key DOD installations and those not within the 300-mile circles. In the control group also, no forecasts were used after leaving a 300-mile circle. Table 3-1 shows the sample sizes in the groups tested.

TABLE 3-1. CONTROL GROUP SAMPLE POPULATION

	WITHIN 300 MILES OF KEY DOD INST.	OUTSIDE 300-MILE CIRCLE	TOTAL
Control Group 1968, -69, -70	224	382	606
Test Group 1971	126*	186	312
TOTAL	350	568	918

*These forecasts were based on fixes at three-hourly intervals.

3. RESULTS

In all three control years the forecasts made near land were significantly superior to those made over open ocean. Table 3-2 compares the average 24-hour forecast errors for the years within the control group.

TABLE 3-2. CONTROL GROUP
AVERAGE 24-HOUR FORECAST ERRORS

	1968	1969	1970	ALL
Within 300 Miles of Key DOD Inst.	91.5	93.4	84.6	89.1
Outside 300-Mile Circle	99.7	101.9	99.5	100.1
All	97.1	98.9	92.7	96.0

From these results one must conclude that, exclusive of other influences, forecasts are superior within the better data region near land.

Table 3-3 compares the average 24-hour forecasts errors from 1971 when three-hourly fixes were required to the control group.

TABLE 3-3. AVERAGE 1971 24-HOUR FORECAST ERROR
COMPARED WITH CONTROL GROUP

	1971	CONTROL GROUP	ALL
Within 300 Miles of Key DOD Inst.	93.9	89.1	90.8
Outside 300-Mile Circle	87.4	100.1	95.9
All	89.7	96.0	93.9

This comparison reveals two striking contrasts. First, 1971 was the best of the four years for forecasts made over open water and secondly 1971 was the worst of the four years for forecasts made within the 300-mile circles.

There are variations from year-to-year that are not explained here, but the conclusion is inescapable that three-hourly fixes not only did not enhance forecasting capability but, in fact, had a detrimental effect.

4. THE PARADOX

The general superiority of forecasts near land to those over open water was not unexpected. The reversal of this superiority solely attributed to more frequent fixes is counter to the meteorologists' long standing tenet that more data leads to better forecasts. This phenomena might be called the meteorologists' paradox "more data--worse forecasts".

Some rationale for this paradox is in order. The following effects are considered contributory:

a. The addition of three-hourly fixes increased the reconnaissance burden by 30% during the time period when a storm was threatening a key DOD installation. The increased burden was accompanied by a proportional increase in the missed-fix frequency--thus more six-hourly fixes were missed resulting in a disruption of the 6- to 12-hour running continuity of movement and forcing increased reliance on shorter term continuity.

b. When a key installation is being threatened, forecasters are tempted to hedge toward short-term trends when these suggest an increased threat. The "course of least regret" (Simpson, 1971) is considered.

c. Short-term trends were being evaluated near land where terrain influences cause erratic motion, thus making the indicated fix-fix movement even less reliable than over open water.

5. CONCLUSIONS

The requirement for three-hourly fixes has been changed to a request basis by operational commanders and then only if resources permit. This would tend to reduce the cases where a three-hourly fix causes the loss of a six-hourly fix.

The objective of the three-hourly fix program was not to improve 24-hour forecasts. This was an expected spin-off which obviously was not realized. The primary purpose of this program was monitoring for early indications of changes in track or intensity. The extent to which this purpose was served was not evaluated directly, but the results of this study tend to indicate that such early indications, at least with regard to track, are likely to be misleading.

B. COMPARISON OF EXPECTED ERRORS FROM VARIOUS RECONNAISSANCE PLATFORMS

1. INTRODUCTION

The tropical cyclone forecaster is constantly confronted with the task of evaluating eye "fixes" from several different reconnaissance platforms. He must determine how much weight to give each fix in determining the best possible estimate of the storm's true position. Unfortunately, this process of determining weighting factors has been rather subjective until recent years. Simpson (1971) has attempted to make this decision process objective by constructing decision ladders to aid the forecaster. Such techniques are needed to introduce consistency into the determination process and to guide the forecaster's reasoning so as to guarantee the selection of the best possible position.

The purpose of this technical note is to report on a preliminary investigation of expected errors associated with various reconnaissance platforms. These errors are computed using the post-analysis "best track" (BT) constructed by the Joint Typhoon Warning Center (JTWC). The probability that an error of a given magnitude will occur can then be empirically derived by grouping the errors into cumulative frequency distributions. The comparison of "probable" errors at any given level of confidence can then be made to determine weights to be used in the decision process.

It should be noted that this is only a preliminary investigation utilizing data from the 1971 typhoon season. A more complete investigation using data from several years is desirable.

2. THE BEST TRACK AS A STANDARD

The JTWC BT is used to compute an "error" for each fix. Since all of the results of this study hinge upon deviations from the post-analysis position, the validity of using the BT as a standard should be addressed before going further.

The BT is constructed several weeks (often months) after a storm occurs. This time lag insures that all available data arrive at the warning center for input into the post-analysis.

The BT is a smooth curve passing as nearly as possible through all fixes and amplifying data. It represents the best guess as to the path of the surface wind center and consists of points defined to the nearest 10th of a degree at six-hourly intervals during the life of a storm. The track is smoothed in speed, direction and maximum wind intensity. All types of fixes are considered; their weaknesses and strong points insofar as known are evaluated to determine proper weights for each fix. Synoptic data is used as a gross error check on fix positions. A storm track with a history of oscillation is allowed to retain that oscillation, where a single point removed from an otherwise smooth track may be partly discounted. Wind estimates are considered to be within 10% of the actual wind.

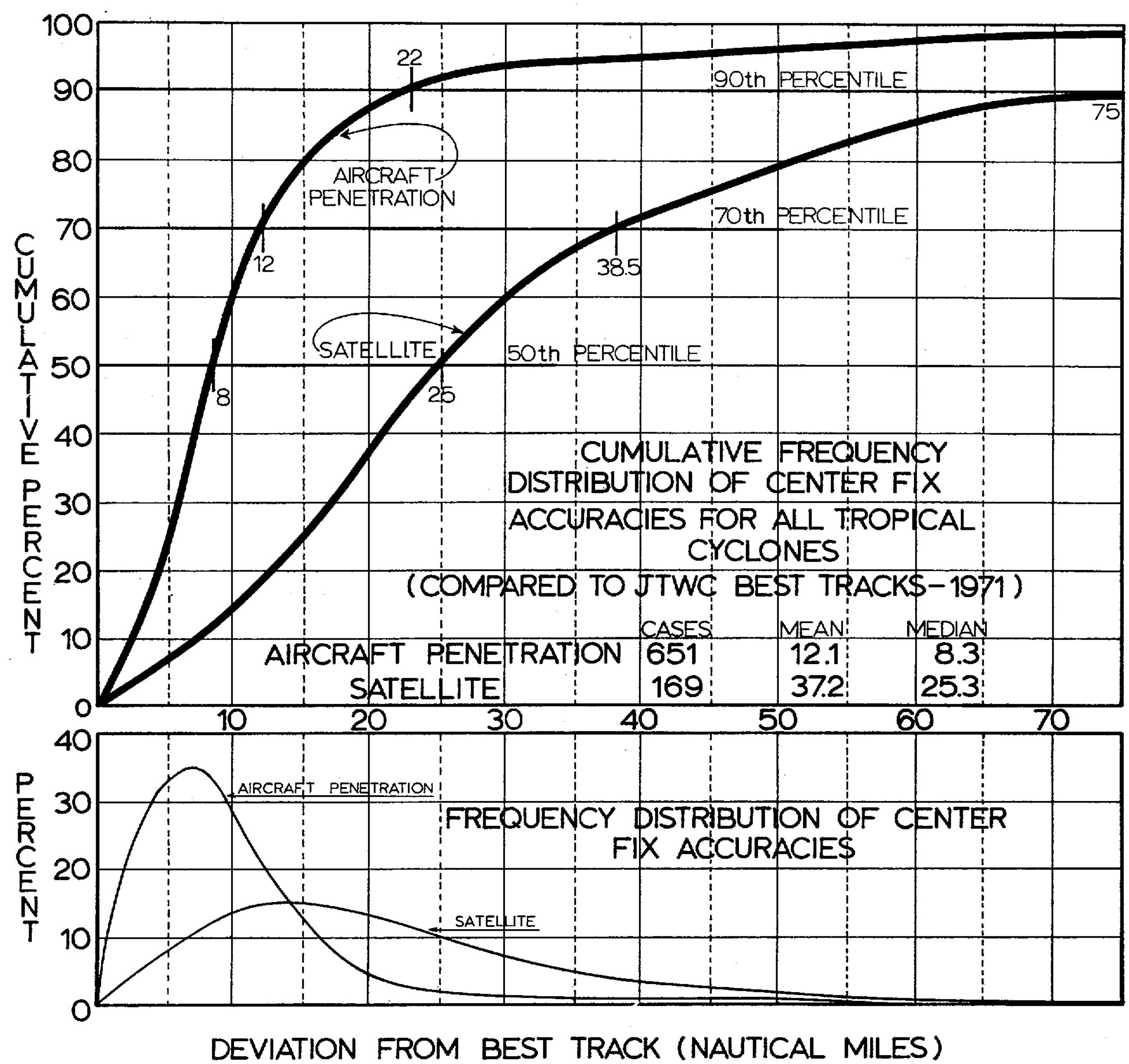
In summary, the BT is the best possible estimate of the actual track of the storm. A certain degree of subjectivity is always present, but in most cases simultaneous information from more than one source results in realistic "bounds" on the possible tracks that could be drawn. Since fixes are normally at six-hour intervals, any real oscillation with a period less than six hours will go undetected. If this oscillation is of the order of 3-5 n mi about the mean track then the fixes will be scattered randomly on either side of this actual track. Thus one should keep in mind that the errors referred to in the following paragraphs may actually be a few miles less. This does not, however, invalidate comparison of relative errors.

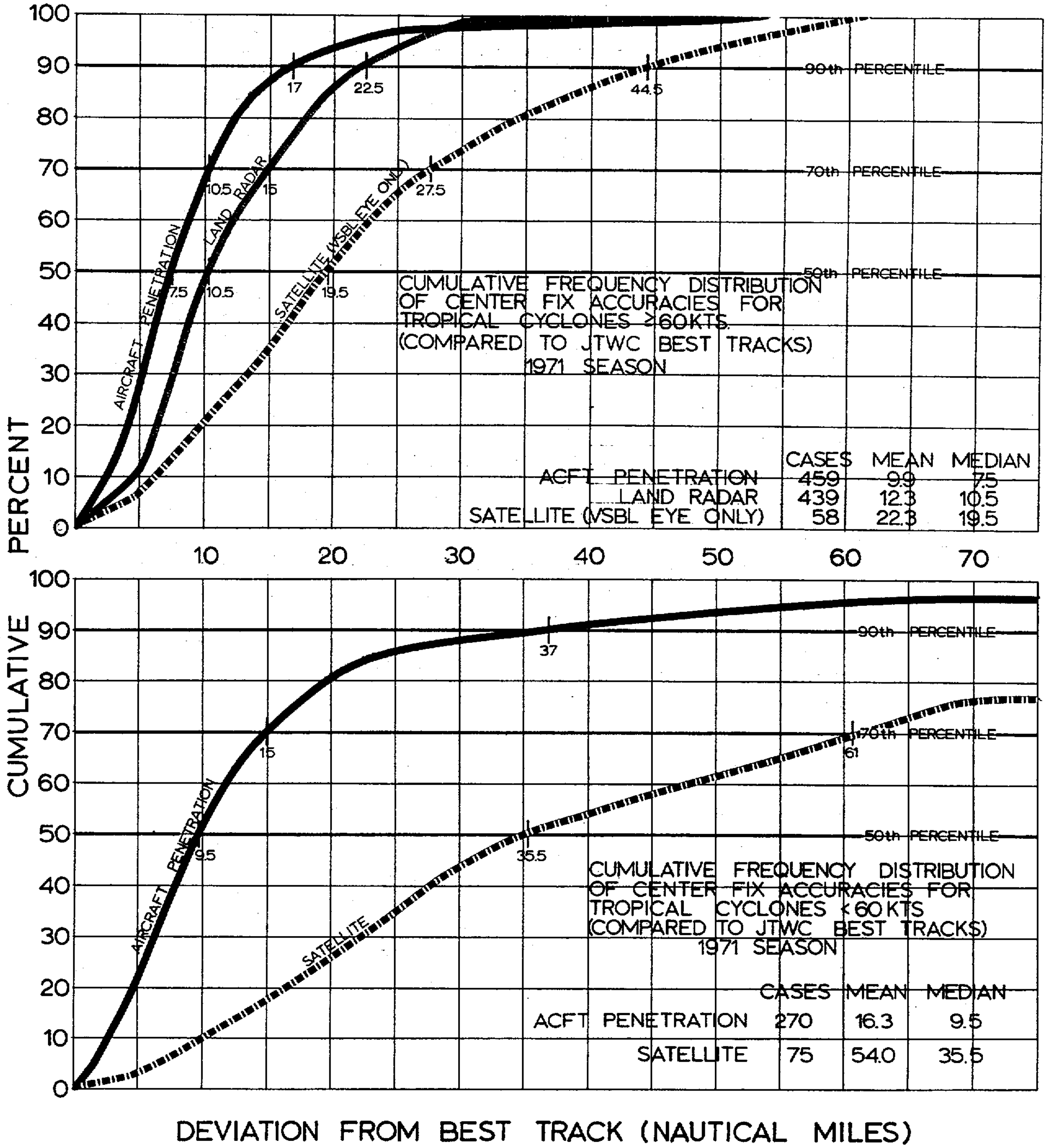
3. TABULATION OF DATA

A computer program was written to process all fixes received during the 1971 typhoon season. Fixes were segregated into three major categories--aircraft, land radar, and satellite.* The error, or deviation from a time interpolated point on the BT was then computed for each fix and all errors for each category were grouped into cumulative frequency distributions.

Figure 3-1 shows cumulative frequency distributions for aircraft fixes made by penetration of the eye and satellite fixes for all tropical cyclones during the year regardless of intensity. It is very evident that aircraft fixes (8 n mi median) are much more accurate than satellite fixes (25 n mi median). At the 70% level the ratio is

*All satellite data was received from the National Environmental Satellite Service.


CUMULATIVE PERCENT
90th PERCENTILE
70th PERCENTILE
50th PERCENTILE
AIRCRAFT PENETRATION
SATELLITE
22
12
8
75
38.5
25
CUMULATIVE FREQUENCY DISTRIBUTION OF CENTER FIX ACCURACIES FOR ALL TROPICAL CYCLONES
(COMPARED TO JTWC BEST TRACKS-1971)
CASES MEAN MEDIAN
AIRCRAFT PENETRATION 651 12.1 8.3
SATELLITE 169 37.2 25.3
PERCENT
AIRCRAFT PENETRATION
SATELLITE
FREQUENCY DISTRIBUTION OF CENTER FIX ACCURACIES
DEVIATION FROM BEST TRACK (NAUTICAL MILES)


CUMULATIVE FREQUENCY DISTRIBUTION OF CENTER FIX ACCURACIES FOR TROPICAL CYCLONES ≥60 KTS. (COMPARED TO JTWC BEST TRACKS) 1971 SEASON
	CASES	MEAN	MEDIAN
ACFT PENETRATION	459	9.9	7.5
LAND RADAR	439	12.3	10.5
SATELLITE (VSBL EYE ONLY)	58	22.3	19.5
AIRCRAFT PENETRATION
LAND RADAR
SATELLITE (VSBL EYE ONLY)
90th PERCENTILE
70th PERCENTILE
50th PERCENTILE
CUMULATIVE FREQUENCY DISTRIBUTION OF CENTER FIX ACCURACIES FOR TROPICAL CYCLONES <60 KTS (COMPARED TO JTWC BEST TRACKS) 1971 SEASON
	CASES	MEAN	MEDIAN
ACFT PENETRATION	270	16.3	9.5
SATELLITE	75	54.0	35.5
AIRCRAFT PENETRATION
SATELLITE
CUMULATIVE PERCENT
DEVIATION FROM BEST TRACK (NAUTICAL MILES)

still about 3:1 with errors of 12.0 and 38.5 n mi for aircraft and satellite respectively.

More insight into the relative accuracies of the reconnaissance platforms can be obtained by segregating the tropical cyclones into two groups--one greater than or equal to 60 kt and the other less than 60 kt. Figure 3-2 shows cumulative frequency distributions for these categories. The lower graph illustrates the most difficult conditions for all reconnaissance platforms. It includes storms which range from weak tropical depressions to strong tropical storms. Aircraft fixes are still below 10 n mi for this category, but satellite fixes, suffering in most cases from the lack of a well-defined eye or center of circulation, have a median error of over 35 n mi and an expected error of over 60 n mi at the 70% level. The upper curve shows expected errors for tropical cyclones 60 kt or greater. The satellite data used in this graph were restricted only to those storms exhibiting visible eyes. This was done purposely so as to use satellite data which was derived under optimum conditions. Again, aircraft penetration is the most accurate method (7.5 n mi median), but land radar is close with a median error of 10.5 n mi. Satellite fixes have a respectable median error of 19.5 n mi. Unfortunately, visible eyes were present in only 25% of the cases during 1971.

4. CONCLUSION

The expected errors derived from the 1971 data are good first-guess estimates which can be applied operationally by the tropical cyclone forecaster. By evaluating expected errors at some arbitrary observed probability level, say 70%, the forecaster can construct circles of probability about each fix to determine the best possible position of the storm. Thus the expected errors can be considered to be inverse weighting factors for each type of fix.

C. RATE OF INTENSIFICATION STATISTICS FOR 1971 TROPICAL CYCLONES

The statistics contained in Table 3-4 are based on development rates determined from individual averages for 37 tropical cyclones during 1971. Studies of the rate of intensification of tropical cyclones have been carried out in the past, e.g. Auchterlonie (1970), Brand (to be published), but none have documented the time sequence of events from the initial birth of the tropical disturbance. The information provided in this table, though based on a relatively small sample illustrates quite well the shorter time periods required for development during the latter months of the year.

TABLE 3-4. RATE OF INTENSIFICATION STATISTICS FOR 1971 TROPICAL CYCLONES

TIME PERIODS	JAN FEB MAR	APR MAY JUN	JUL AUG SEP	OCT NOV DEC	ANNUAL AVERAGE
INITIAL DETECTION* TO TROPICAL DEPRESSION	5.2 days	4.0 days	2.6 days	2.0 days	3.0 days
INITIAL DETECTION* TO TROPICAL STORM	6.5 days	6.0 days	3.8 days	3.5 days	4.3 days
INITIAL DETECTION* TO TYPHOON	---	8.6 days	5.3 days	4.8 days	6.0 days
TROPICAL DEPRESSION TO TYPHOON	---	4.6 days	2.7 days	2.8 days	3.0 days
TROPICAL STORM TO TYPHOON	---	2.6 days	1.5 days	1.3 days	1.7 days

*Initial detection of the tropical disturbance.

D. JTWC WARNING TIMES

JTWC issues typhoon warnings at fixed times six hours apart (four per day) because this schedule matches the meaningful time variation in tropical cyclone parameters, provides for optimum utilization of forecast resources, and best satisfies the requirements of the JTWC customer.

First of all, climatology shows that the real variations in the pressure, temperature, and wind fields associated with a tropical cyclone occur predominantly on the order of hours. Likewise, the position and velocity of a storm changes on this same time scale. To put meaningful information into a typhoon warning, it is imperative that the storm measurement/warning frequency match the frequency of real variation in these key storm parameters. If the time between measurements/warnings were on the order of tens of hours (twice a day, daily, etc.), significant changes would occur between the measurements/warnings. On the other hand, if this time period were on the order of tenths of hours (minutes), various types of noise would obscure the real variation in the storm parameters. Thus, the nature of the phenomenon itself dictates that the time between warnings be on the order of hours.

Secondly, and perhaps more importantly, JTWC warning times are constrained by the scheduled availability of data, manpower, and time resources. The 6/12-hour frequency of meteorological observations established by international agreement determines the receipt frequency of data fields and numerical progs used in JTWC subjective and objective techniques. Warnings issued more frequently than every six hours would contain no new information, while warnings issued less frequently than every 6/12 hours would neglect new information.

In like manner, efficient utilization of reconnaissance aircraft requires specific limits on the time between warnings. If the warning times, and therefore the fix times, are scheduled approximately six hours apart; one aircraft (WC-130) can normally handle two fixes in one mission, and two aircraft can handle the four daily fixes on any one storm. On the other hand, a period longer than six hours, such as eight hours, would normally require one mission per fix thereby yielding a smaller number of fixes for a greater expenditure of aircraft resources.

Additionally, the 12-hour watch routine at JTWC is built around the two fixed warning times falling within that watch. Each task is sequenced in a coordinated step-wise fashion toward the construction of a sound warning. This routine has been standardized from one watch to the next and also facilitates the training of new personnel. Variation of the task schedule from one watch to the next would confuse and complicate the warning process resulting in the loss of valuable time.

Finally, and perhaps most important, JTWC warning times must satisfy the requirements of the customer. JTWC customers want warnings as often as new data is available, thereby necessitating warnings at least every six hours. In addition, the customer's mission planning and decision-making processes are designed to incorporate JTWC warning information at specific times each day. Field commanders would not readily change their briefing times each day to fit the JTWC warning times. This requires the warning interval to be a number of hours that will evenly divide into 24.

The above constraints taken together require four warnings per day at fixed times six hours apart. The only latitude remaining is the choice of the specific warning hours within the day. Based on operational experience JTWC has found 0000Z, 0600Z, 1200Z, and 1800Z to be optimum.

E. A STATISTICAL STUDY OF RAPID DEEPENING IN TYPHOONS

1. INTRODUCTION

The occurrence of rapid deepening is a subject of concern to the typhoon forecaster as this process is often "explosive" in nature, taking place in a time frame of a day or less. Little skill has been exhibited in foreseeing these events which may have potentially disastrous consequences to forces afloat or ashore due to the short reaction time to afford protective measures.

Other than Ito (1961) and Jordan (1961), little documentation on rapid intensification of typhoons has appeared in literature. This note is a brief statistical review utilizing a larger data base which has accumulated since the appearance of the aforementioned studies.

2. PROCEDURE

The data used were aircraft reconnaissance reports contained in past copies of the Annual Typhoon Report prepared by Fleet Weather Central/Joint Typhoon Warning Center, Guam. Rapid intensification was measured by means of the central pressure of the typhoon. This parameter is considered a more reliable and conservative measure of intensity than the maximum winds and is not as likely to be biased by sampling procedures (Colon, 1963 and FWC/JTWC, 1970).

In order to obtain a meaningful sample, several restrictive criteria were introduced. Since the majority of typhoon penetrations were at the 700-mb level, a regression equation developed by Jordan (1957) employing the minimum 700-mb height was used to screen for errors in central pressures obtained by dropsonde. Since geopotential heights at the 700-mb level generally were not available in Annual Typhoon Report's prior to 1956, the sample was limited to the 16-year period from 1956 to 1971.

The 24-hour interval was chosen for study since reconnaissance observations were usually available at least once a day, and this interval represents the time period during which major last-minute precautions such as aircraft evacuation, ship sortie, and evasion can still be taken. As intervals between aircraft fixes were often irregular, a limit of ±3 hours was placed on the end points of the 24-hour period to insure that the rates of deepening would be representative. All data were normalized to a 24-hour interval. The above restrictions eliminated 57 of the

312 typhoons occurring in the 16-year period. The remaining 255* typhoons are considered to constitute a reasonable sample upon which to build a reliable climatology.

A frequency distribution of the useable data as to maximum 24-hour deepening is shown in Figure 3-3. The highest frequency appears in the 10 to 30 mb/24-hour interval centered on a median of 23 mb/24 hour. In this note, intensification of ⩾30 mb in 24 hours (1.25 mb/hour) will be considered as the criteria for rapid deepening.

Of the 255 typhoons in the sample, 37% or 95 storms had at least one case of 24-hour deepening ⩾30 mb during their histories (Table 3-5). For purposes of perspective, during the same period 1956-1971, only 9 of 87 (or 10%) of Atlantic hurricanes exhibited a similar 30 mb/24-hour deepening.**

3. THE DEEPENING PERIOD

Frequencies of central pressures of typhoons when rapid deepening began are displayed in Figure 3-4. These data indicate the majority of the deepening (81%) commenced in the interval 960 to 989 mb with a peak of 35% occurring for the 970 and 979 mb category. Using the equation derived by Takahashi (1939), in which a mean pressure of 975 mb for the interval equates to 80 kt, this would seem to indicate a certain stage of development must be reached prior to the start of rapid deepening.

A comparison was made between the time of the commencement of rapid deepening relative to the time typhoon force was first attained. Figure 3-5 shows the frequency of the onset of rapid deepening in terms of time before, or after, typhoon force (64 kt) was attained. To minimize the effect of time-interval variations, relative times were rounded to the nearest even 12 hours. Figure 3-6 shows that in 75% of the cases under consideration rapid deepening occurred within 36 hours after typhoon generation. It is also evident that 91% of the cases begin at or after typhoon strength is achieved.

The data presented in Figures 3-4 and 3-5 support a hypothesis that a certain organization to the tropical

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*Includes Kit, Jan 1972.

**Source - Annual hurricane summaries appearing in Monthly Weather Review.

cyclone must be achieved before rapid deepening can occur. Jordan and Frank (1961) and Dunn and Miller (1960) have noted that the formation of an eye closely corresponds with the development of hurricane-force winds. The presence of an eye wall probably is the prerequisite before the central pressure will show a rapid rate of reduction.

On the other end of the time frame for deepening, a two-day limit appears to exist if rapid intensification is to occur, since 84% of the sample under consideration began maximum deepening prior to 60 hours after the onset of typhoon force winds. A few obvious reasons, such as short-lived typhoons that strike land or those that have recurved, probably account for much of this. However, many typhoons fall into neither group. For these cases there are apparently some mechanisms for rapid deepening available soon after the attainment of typhoon force which is unlikely to be available later.

4. EXTREMES

A distribution of the frequencies of the ⩾30 mb/24-hour cases by 10-mb intervals appears in Figure 3-6. Extremes of ⩾60 mb/24 hour (2.5 mb/hour), or twice the rapid deepening rate under consideration, were in evidence in 19 (or 20%) of the 95 rapid-deepening cases during the 16-year period. Two of the most extreme intensification rates occurred in typhoons Ida (1958 which culminated in an 86-mb drop in a 22 1/2-hour period (3.8 mb/hour) and Irma (1971) in which a 97-mb drop in 24 1/2 hours (4 mb/hour) was recorded.

Reconnaissance data were frequent enough to determine a maximum 12-hour rate for 75 of the 95 cases of rapid deepening while a maximum 6-hour rate could be found for 65 cases (Table 3-6). Thirty-seven typhoons displayed an intensification rate of ⩾30 mb in 12 hours (2.5 mb/hour) while four achieved ⩾30 mb in 6 hours (5 mb/hour). These cases fall in a category of their own and must be regarded as extreme examples of "explosive" deepening.

5. SEASONAL DISTRIBUTION

The yearly occurrence of ⩾30 mb deepening per 24 hours gives a rather uneven distribution ranging from ten in 1968 to one in 1960 during the period of the sample (Table 3-5). However, with 18% of the total typhoons during that interval not useable due to the restrictions of the study, this must be considered only a partial picture.

The total monthly frequency shown in Table 3-7 displays a distribution with greatest occurrences from July to November (75%). Two peaks show in the data; the major one is in September which coincides with the month of greatest super typhoon activity (FWC/JTWC, 1970). The secondary peak takes place in November; however, this month exhibits a higher probability of typhoons undergoing rapid deepening than in September. Comparing the data sample to the total number of typhoons occurring during the period 1956-1971 by month--September with 65 typhoons gave a ratio of 41%, while the 29 typhoons for November resulted in a ratio of 52%.

6. GEOGRAPHICAL DISTRIBUTION

The distribution of segments of the 95 typhoons where deepening ⩾30 mb/24 hour took place is displayed in Figure 3-7. Ninety-three percent of the tracks were on a heading between 350°-250° which would serve to emphasize that maximum deepening occurs before recurvature. This supports Riehl's (1971) findings which indicated that maximum intensity is reached prior to recurvature.

The majority of the track segments are concentrated in the latitude belt between 10N and 20N and longitudes of 125E and 155E. Solid lines are for typhoons occurring between July and November and represent the main season while the dashed lines are typhoons which occurred between December and June. The lone occurrence documented in the South China Sea was Harriet (1971) while the track with the highest latitude was described by Trix (1971).

The points of initial rapid deepening are displayed in Figure 3-8. The latitude and longitude of these points were averaged for each five-degree Marsden square to represent the centroid of the points contained in the square. The areas of maximum frequency are concentrated in the west central Philippine Sea and just east of the Marianas island chain. This resembles the double maximum distribution shown to occur in the first points of super typhoon intensity (FWC/JTWC, 1970 and Fung, 1970) for minimum pressure in typhoons. However, the rapid deepening maximum is displaced 5 degrees to the east of the first study mentioned--a logical location upstream for westward moving typhoons. The display does not show any significant minimum between the two maximum centers as charted in the 1970 Annual Typhoon Report.

7. SUMMARY

Data for the years 1956 through 1971 indicate occurrence of 95 cases of rapid deepening to the extent of $\geq$30 mb in a 24-hour interval. Extremes of over twice this rate of deepening were noted as instances of $\geq$30 mb in 12 hours were not uncommon (15% of useable sample). The maximum frequency (75%) was found to begin in the period from the point where initial typhoon force was achieved to 36 hours afterwards. Seventy-five percent of the rapid deepening cases fell in the interval between July and November with the highest probability of rapid deepening appearing in September and November. Track segments of typhoons considered showed maximum deepening was predominant prior to recurvature and was primarily a feature occurring from 155E to the Philippine archipelago between latitudes of 10N and 20N with local maxima of initial rapid deepening in the west central Philippine Sea and just east of the Marianas.

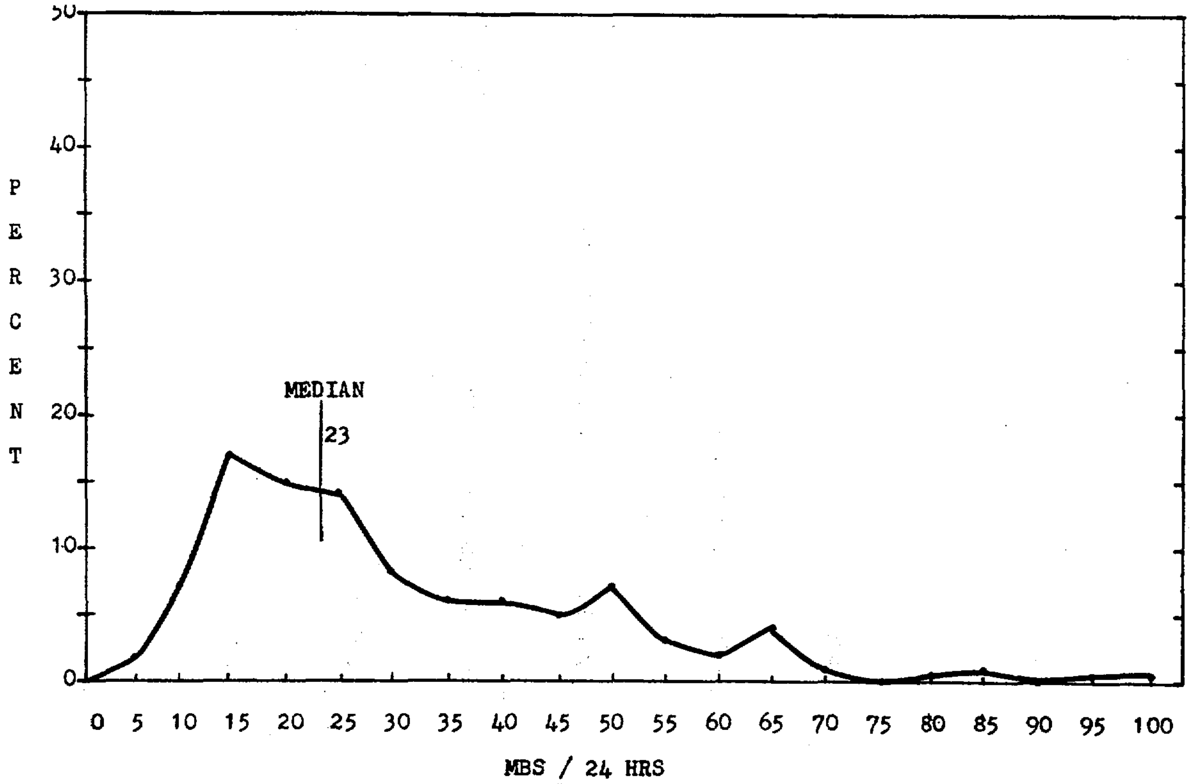


Figure 3-3. Frequency Distribution of Maximum 24 Hour Deepening of Typhoons, 1956-1971, 255 cases.

TABLE 3-5. MAXIMUM 24-HR DEEPENING (MB) OF TYPHOONS 1956-1971

YEAR	≥30	<30	<30 >30	NOT USED	ALL
1971*	10	11	21	4	25
1970	7	5	12	-	12
1969	8	5	13	-	13
1968	10	10	20	-	20
1967	6	11	17	3	20
1966	2	16	18	2	20
1965	6	10	16	5	21
1964	6	15	21	5	26
1963	6	10	16	3	19
1962	4	15	19	5	24
1961	4	7	11	9	20
1960	1	10	11	8	19
1959	9	6	15	2	17
1958	7	11	18	2	20
1957	6	9	15	3	18
1956	3	9	12	6	18
TOTAL	95	160	255	57	312
% OF TOTAL TYPHOONS	37%	63%	82%	18%	100%

*Includes Kit (Jan 1972)

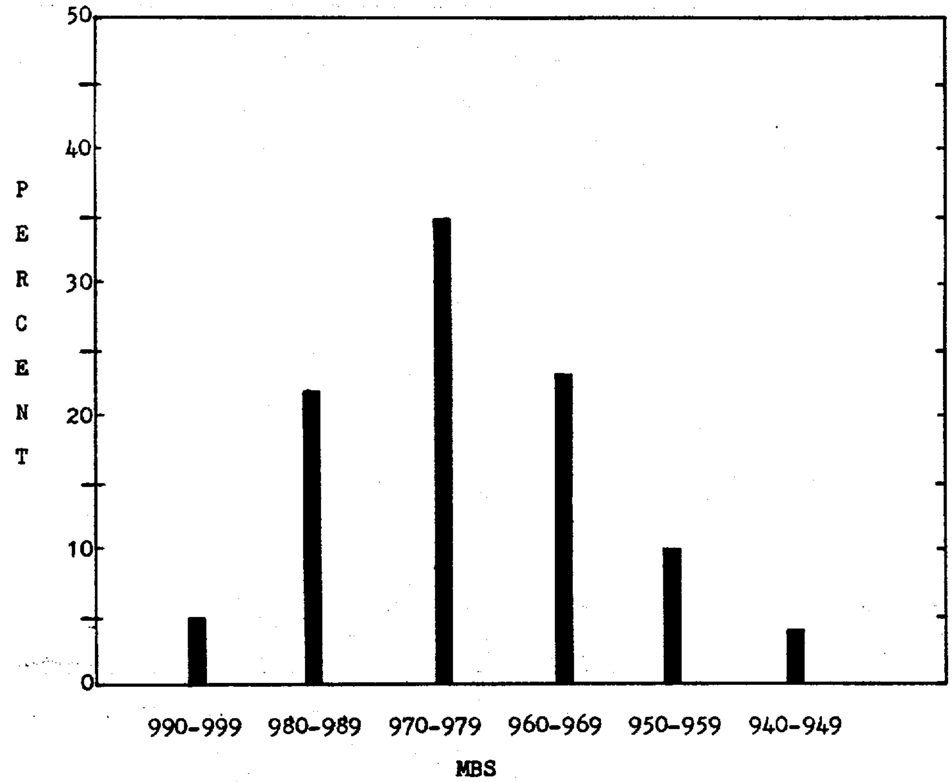


Figure 3-4. Frequency Distribution of Central Pressure for the Onset of Rapid Deepening (≥30 mb/24 hour), 1956-1971, 95 cases.

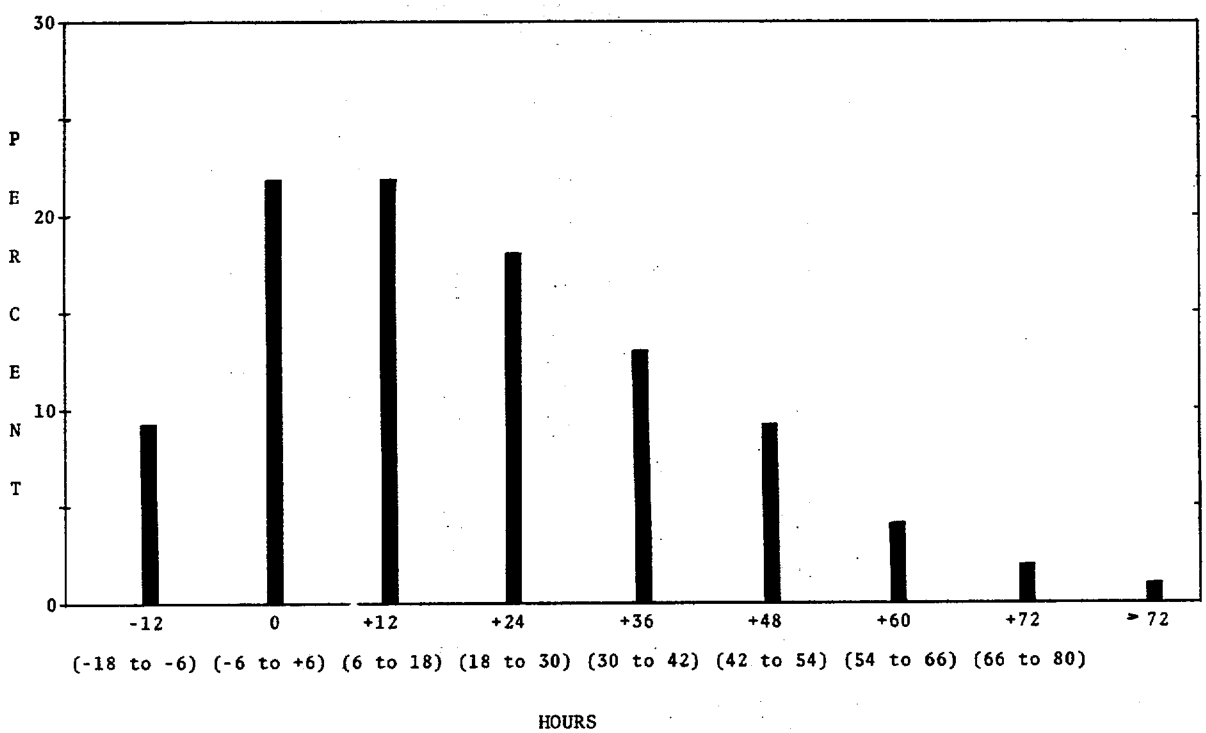


Figure 3-5. Frequency Distribution for Initial Point of Rapid Deepening (≥30 mb/24 hour) Compared to Onset of Typhoon Force Winds, 1956-1971, 95 cases.

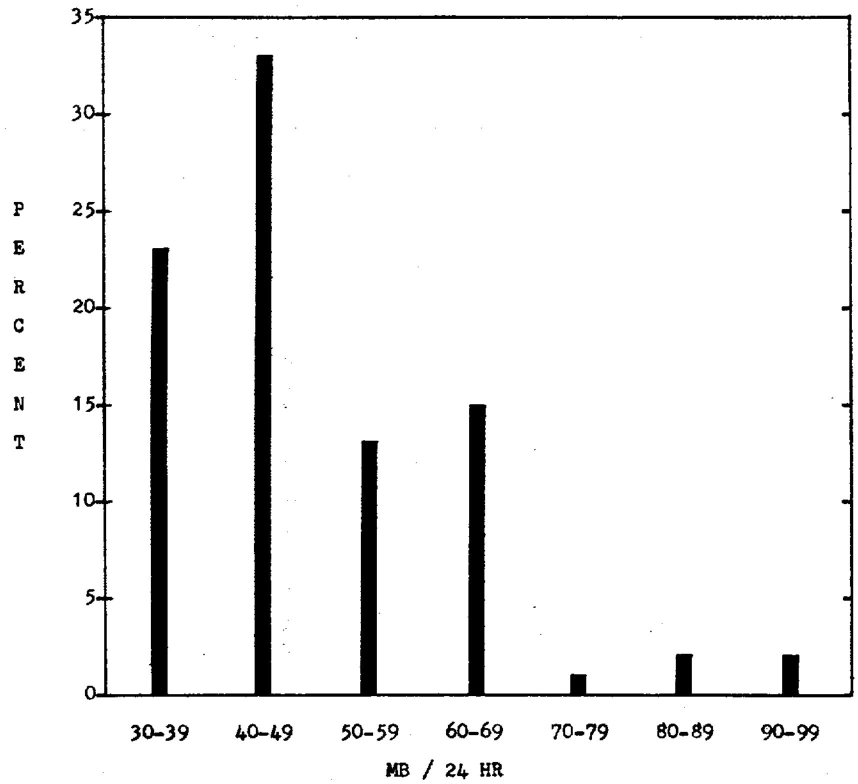


Figure 3-6. Frequency Distribution of Cases of ≥30 mb (10-mb intervals), 1956-1971, 95 cases.

TABLE 3-6. RAPID DEEPENING (≥30 MB) OF TYPHOONS 1956-171 FOR 12- AND 6-HR PERIODS

YEAR	12 HR ≥30 MB	6 HR ≥30 MB
1971*	6	1
1970	4	-
1969	-	-
1968	3	-
1967	3	-
1966	1	2
1965	1	-
1964	3	-
1963	2	-
1962	2	-
1961	2	-
1960	1	-
1959	4	-
1958	4	1
1957	4	-
1956	-	-
TOTAL	40	4
% OF ≥30 MB/24 HR	42%	4%
% OF ALL SAMPLE	16%	2%

*Includes Kit, Jan 1972.

TABLE 3-7. MONTHLY VARIATIONS 1956-1971 OF TYPHOONS DEEPENING ≥30 MB/24 HR

MONTH	≥30 MB/24 HR	TOTAL TYPHOONS OCCURRING IN MONTH	RATIO
JAN*	1	5	
FEB	0	1	
MAR	1	3	
APR	4	14	
MAY	1	15	
JUN	5	19	
JUL	10	46	22%
AUG	18	65	28%
SEP	23	56	41%
OCT	12	45	27%
NOV	15	29	52%
DEC	4	10	

*Includes Kit, 1972.

Note: Ratio computed only for months with total typhoon count of ≥25.

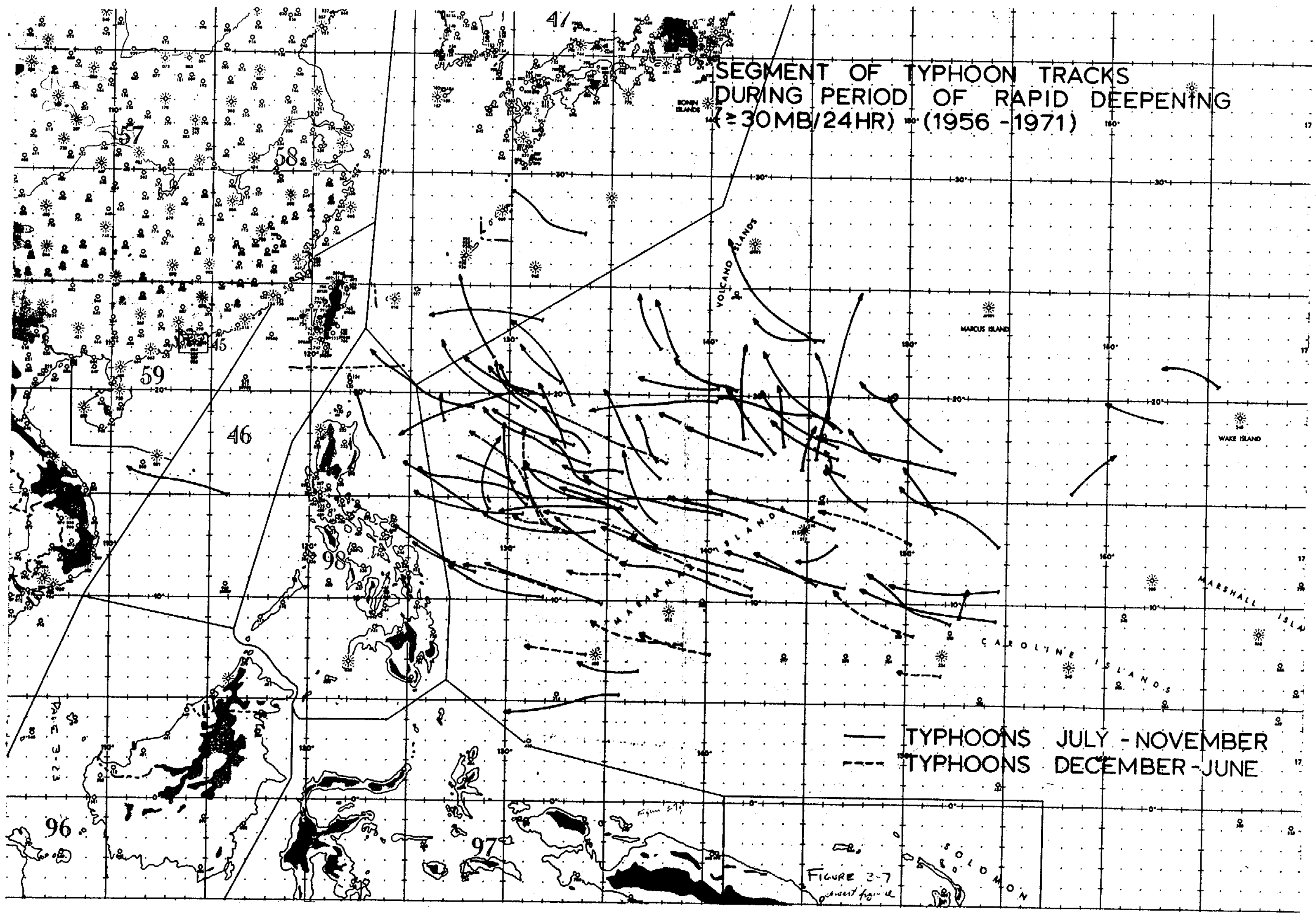
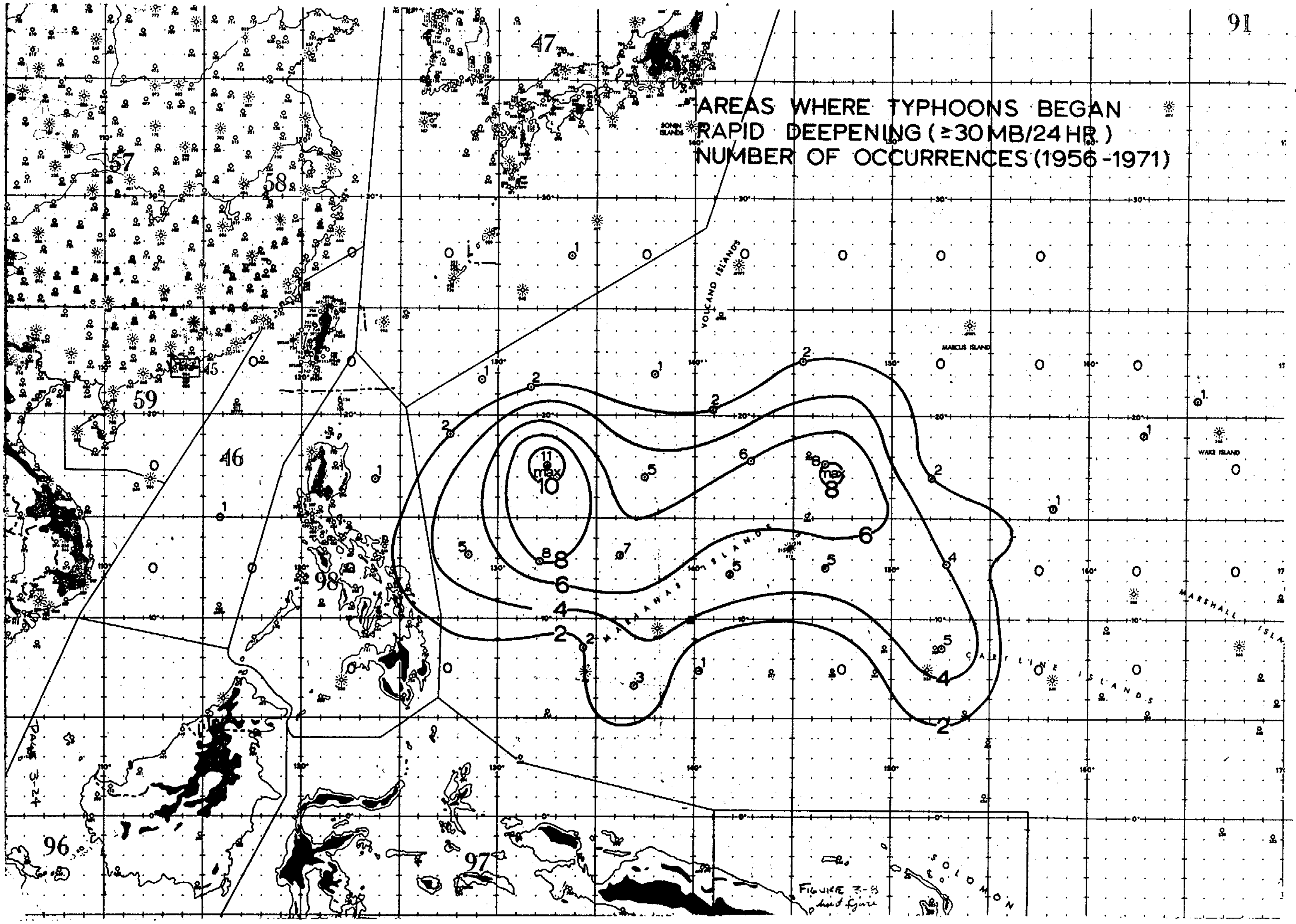

SEGMENT OF TYPHOON TRACKS
DURING PERIOD OF RAPID DEEPENING
(≥30MB/24HR) (1956 - 1971)
VOLCANO ISLANDS
MARCUS ISLAND
WAKE ISLAND
MARIANA ISLANDS
CAROLINE ISLANDS
MARSHALL ISL
SOLOMON
TYPHOONS JULY - NOVEMBER
TYPHOONS DECEMBER - JUNE
57
58
59
46
45
47
98
96
97

Figure 3-7.



91
AREAS WHERE TYPHOONS BEGAN
RAPID DEEPENING (≥30 MB/24 HR)
NUMBER OF OCCURRENCES (1956-1971)
VOLCANO ISLANDS
MARCUS ISLAND
WAKE ISLAND
MARIANAS ISLANDS
CAROLINE ISLANDS
MARSHALL ISLA
SOLOMON

Figure 3-8.

F. COMPARISON OF OBJECTIVE TECHNIQUES

1. GENERAL

Verification of objective forecasting techniques has been continuous since 1967 although year-to-year modifications and improvements have prevented any long period comparison of more than a few of the techniques. None of the objective forecasts used now go beyond the simple steering concept of a point vortex in a smoothed flow field with adjustments based on past movement. Development and its important relationship to movement are excluded in all objective forecasts.

TYFOON, a new statistical analog technique for western Pacific typhoons (Jarrell and Somervell, 1970) that closely resembles HURRAN, its Atlantic counterpart (Hope, et al 1970), was first tested during the 1970 season. While designed as a forecast aid, verification is presented here along with the other objective techniques. This technique provides objective forecasts out to 72 hours.

2. DISCUSSION OF OBJECTIVE TECHNIQUES

a. EXTRAPOLATION - Past 12-hour movement is extrapolated to 24 and 48 hours.

b. ARAKAWA (1963) - Grid overlay values of surface pressure are entered into regression equations and hand-computed for storms 50 kt or greater.

c. HATRACK 700 mb, 500 mb (Hardie, 1967) - Point vortex advected on the 700 mb and 500 mb analysis or prognostic SR (space mean) field in six-hour time steps up to forecast period of 66 hours (without bias correction).

d. RENARD 700/500 - This technique is basically the HATRACK scheme with an adjustment to correct for recent errors extrapolated into the future. This "bias adjustment" is similar to that proposed by Renard et al (1970) except no limits are imposed on the bias growth rate.

e. TYRACK - Tropical cyclone movement forecast on FWC Pearl tropical fields (Hubert, 1968) with capability for subjective program control. This technique will no longer be available at JTWC since the FLEWEACEN Pearl Harbor streamline fields are being replaced with the FLENUMWEACEN Monterey Global Band field and there are no current plans to redesign the TYRACK program to operate on these fields.

f. TYFOON (Jarrell and Somervell, 1970) - Program outputs forecast positions as the centers of probability ellipses out to 72 hours based on a group of analog storms which occurred within a time/space envelope centered about the date and position of the storm being forecast. Ellipses are based on the analog population weighted according to similarity to the existing storm.

3. TESTING AND RESULTS

Table 3-8 presents a homogeneous comparison of all techniques used. The official JTWC forecast is included for comparison in those cases where at least one objective technique was used. The comparison reveals that the TYFOON program (weighted climo) is superior to all existing techniques. There is currently at JTWC a research effort underway to systematically examine all aspects of TYFOON in an effort to eliminate known limitations to this program. Some modifications to TYFOON will probably be instituted before the main 1972 season.

TABLE 3-8. OBJECTIVE TECHNIQUES VERIFICATION

NUMBER OF CASES	X-AXIS TECHNIQUE ERROR
Y-AXIS TECHNIQUE ERROR	ERROR DIFFERENCE Y-X

24-HOUR

	JTWC	XTRP	ARKW	HT7P	HT5P	RD7M	RD5M	TYRK	CLIW
JTWC	577 109 109 0								
XTRP	427 99 118 19	429 118 118 0							
ARKW	57 79 102 23	54 104 105 1	57 102 102 0						
HT7P	89 104 232 129	78 110 236 125	23 110 230 120	89 232 232 0					
HT5P	89 103 233 130	77 108 239 132	22 112 222 110	86 232 234 3	89 233 233 0				
RD7M	60 104 127 23	53 110 114 4	18 110 109 -1	60 230 127 -103	59 234 127 -107	60 127 127 0			
RD5M	63 102 128 27	55 108 119 11	20 110 104 -6	61 230 131 -99	62 237 129 -108	60 127 132 5	63 128 128 0		
TYRK	213 96 133 37	188 104 130 26	43 97 118 21	76 224 133 -91	75 227 134 -93	50 127 125 -3	52 128 126 -2	213 133 133 0	
CLIW	146 98 104 5	114 108 100 -8	28 94 95 1	41 235 113 -122	41 236 112 -125	26 126 113 -13	29 128 108 -20	105 143 107 -36	150 104 104 0

JTWC - OFFICIAL JTWC SUBJECTIVE FORECAST
XTRP - EXTRAPOLATION
ARKW - ARAKAWA
HT7P - HATRACK 700 MB PROG
HT5P - HATRACK 500 MB PROG
RD7M - RENARD MOD TO HATRACK 700
RD5M - RENARD MOD TO HATRACK 500
TYRK - TYRACK
CLIW - TYFOON (WEIGHTED CLIMO)

48-HOUR

	JTWC	XTRP	ARKW	HT7P	HT5P	RD7M	RD5M	TYRK	CLIW
JTWC	375 208 208 0								
XTRP	283 195 246 50	293 246 246 0							
ARKW	40 157 245 88	36 221 247 26	40 245 245 0						
HT7P	60 180 419 239	57 236 419 183	18 251 376 124	63 415 415 0					
HT5P	63 179 386 207	60 230 387 157	19 247 341 94	62 411 383 -29	66 382 382 0				
RD7M	37 178 240 62	35 242 244 2	14 251 206 -45	38 379 239 -140	38 359 239 -121	38 239 239 0			
RD5M	41 169 222 52	39 231 218 -13	16 250 190 -60	39 380 226 -154	42 357 220 -137	38 239 227 -11	42 220 220 0		
TYRK	156 186 307 121	141 225 310 85	31 239 288 49	52 401 290 -110	55 365 296 -69	31 251 268 17	35 219 291 72	164 314 314 0	
CLIW	110 189 207 19	90 214 205 -8	22 222 182 -40	30 435 218 -217	31 376 218 -158	18 263 222 -41	20 216 218 2	85 342 217 -125	126 209 209 0

72-HOUR

	JTWC	CLIW
JTWC	122 314 314 0	
CLIW	47 280 306 27	89 301 301 0

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